An underwater photograph showing a dense patch of Tapegrass (Vallisneria spiralis) in a pond. The long, thin, green leaves of the plant are visible, extending from the bottom towards the surface. The water is slightly murky, and the background is a dark, brownish-green color.

Risk analysis of non-native Tapegrass (Vallisneria spiralis) in the Netherlands

By J. Matthews, R. Beringen, F.P.L. Collas, K.R. Koopman, B. Odé, R. Pot, L.B. Sparrius, J.L.C.H. van Valkenburg, L.N.H. Verbrugge & R.S.E.W. Leuven

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Summary

Tapegrass (*Vallisneria spiralis*) is an aquatic plant, non-native to the Netherlands. It was first recorded in the Netherlands in 1960 in the canal Maastricht-Luik and was recently observed in the Biesbosch area in the Rhine-Meuse estuary, a sand excavation pit in the floodplains of the Nederrijn River near Grebbeberg and Eindhovens canal. Previously, there was a lack of knowledge regarding the probability of arrival, establishment and spread, endangered areas, (potential) impacts and options for management of *V. spiralis* in the Netherlands. This report is the synthesis of results obtained from a literature study, field observations and expert consultation that address this knowledge gap in the form of a knowledge document. The knowledge document was used to assess the ecological risk using the Belgian ISEIA protocol. Socio-economic and public health risks were assessed separately as these do not form part of the ISEIA protocol. Recommendations were then made regarding management options relevant to the situation found in the Netherlands.

V. spiralis is a widely used aquarium plant, the main route of arrival is most likely the ornamental plant trade. numerous hobbyists were found that were selling the species on the internet. We predict that without management intervention, *V. spiralis* introductions will continue leading to a potential increase in its distribution. The probability of arrival was judged to be high.

V. spiralis has been recorded in the Netherlands since 1960. Throughout the 20th century the records of *V. spiralis* establishment varied between 1 and 2 kilometre squares. During the 21st century the yearly number of kilometre squares where *V. spiralis* has established increased to a maximum of eleven records in 2011. The current recorded distribution of *V. spiralis* is characterised by isolated populations. However, its actual distribution may be more extensive as it is a very inconspicuous species.

After considering information on physiological tolerances, growth performance and current occurrence it is expected that the establishment of *V. spiralis* in the Netherlands will be mainly limited by the minimum water temperature. The winter temperature in most inland water bodies in our country will be below the tolerance value of *V. spiralis*. This particularly holds for the shallow parts of rivers and lakes. Therefore, the probability of establishment, based on current available data, was judged to be low.

V. spiralis displays a strong reproductive potential by producing seeds and can spread in the form of fragments that may be transported in water or by waterfowl. However, plants most often spread using runners which can lead to dense stands. The probability of spread was judged to be high.

Four factors are considered as part of the ISEIA protocol: dispersion potential and invasiveness, colonisation of high conservation habitats, adverse impacts on native species and alteration of ecosystem functions.

- Dispersion potential and invasiveness: Since it was first recorded in the Netherlands in 1960, dispersal of *V. spiralis* has been slow and records remain limited to five

distant locations. Plants are imported and sold as part of the plant trade and may be released to the freshwater network by hobbyists. The species is able to reproduce vegetatively and can disperse via water, humans and bird vectors, displaying a strong reproductive potential. In future, the potential habitat area of *V. spiralis* may increase in the intertidal freshwater estuarine areas of the rivers Rhine and Meuse. Here, extreme low water levels do not occur during winter. This, in combination with the occurrence of large areas of shallow water (1 m depth approximately) which warm rapidly in spring and summer and do not freeze to the bottom in winter, makes this water type a suitable habitat for *V. spiralis*. The addition of river water warmed by thermal discharges and of improved general quality increases this suitability. Moreover, river temperatures are expected to increase further in future due to the effects of climate change.

- Colonisation of high conservation habitats: The only recent known areas of high conservation habitats colonized by *V. spiralis* in the Netherlands are the freshwater tidal area of the Biesbosch-Merwede and a sand excavation pit in the floodplains along the Nederrijn River near Grebbeberg (both sites are located in a Natura 2000 area). The abundance of *V. spiralis* in the Biesbosch-Merwede has increased, while in the sand excavation pit near Grebbeberg an increase in abundance has not been observed.
- Adverse impacts to native species: There is no evidence to suggest that *V. spiralis* has a negative impact on native species in the Netherlands. Field observations suggest that there are no signs that native aquatic plant species are displaced by *V. spiralis* in the Biesbosch-Merwede area. In other European countries, with more suitable climates, *V. spiralis* has been present for a longer period than in the Netherlands. However, nowhere in these countries is *V. spiralis* regarded as a pest species. Therefore, it is expected that in the future, even with a potential range expansion, that negative impacts on native species will be minimal.
- Alteration to ecosystem functions: No adverse effects of *V. spiralis* on ecosystem functioning in the Netherlands were identified. In addition, there is no evidence for adverse alterations of ecosystem functioning from other European countries with more suitable climates and where *V. spiralis* has been present for a longer period than in the Netherlands. Therefore, it is expected that in the future, even with a potential range expansion, that negative alterations to ecosystem function will be minimal.

V. spiralis is classified in the low risk category of the ISEIA protocol and C1 in the BFIS list, according to its recorded distribution. Category C1 includes species with distributions characterised by isolated populations with a low environmental hazard.

Although *V. spiralis* has been recorded in the Netherlands since 1960, its recorded distribution is still limited. Moreover, no impacts on native species or on the functioning of ecosystems have been identified here. It is expected that the distribution of *V. spiralis* will not increase significantly in the future, that ecological and socio-economic impact will remain low and that *V. spiralis* will remain classified as a C1 species.

It should be noted that *V. spiralis* is a very inconspicuous species. Most locations where the plants exist are almost invisible from on shore or from a boat making them difficult to locate. Therefore, there may well be discrepancies between the actual distribution and the recorded distribution of *V. spiralis* within the Netherlands. If the actual distribution of *V. spiralis* is higher than the recorded distribution then a re-classification of the species to a higher BFIS category would be required, for example C2. This category defines species characterised by a restricted range and a low environmental hazard.

Socio-economic impacts resulting from *V. spiralis* are limited in the Netherlands. Information from other countries indicates that *V. spiralis* is known to affect the drainage of different water bodies as well as impede recreational use.

There was no information found concerning the public health effects of *V. spiralis* during the literature study or in communications with project partners.

Banning of sale of *V. spiralis* via the plant trade is the most effective method of controlling its spread. Once established the management of plants is challenging. Managers may first wish to consider observing the dispersal potential of individual populations of *V. spiralis* prior to instigating active management. If populations become problematic (e.g. in cases of water-flow obstruction), isolation may be considered. This will facilitate the elimination of the species as was observed for isolated populations in Eijsden and Maastricht and other locations within the Netherlands. Costs and the risk of facilitating reproduction through fragmentation together with the limited dispersal potential of *V. spiralis* observed in the Netherlands since 1960, count against the early implementation of weed cutting measures.

1. Introduction

1.1 Background and problem statement

The Tapegrass (*Vallisneria spiralis*) is native in Northern Africa, Southern Europe and Asia. This plant species was first recorded in the Netherlands in 1960 in the canal Maastricht-Luik and was recently observed in the Biesbosch area in the Rhine-Meuse estuary (Boesveld, personal communication). At the start of this project, there was a lack of knowledge regarding the pathways for introduction, vectors for spread, key factors for dispersion and invasiveness, and (potential) effects of *V. spiralis* in the Netherlands.

To support decision making with regard to the design of measures to prevent ecological, socio-economical and public health effects, the Netherlands Food and Consumer Product Safety Authority of the Ministry of Economic Affairs, Agriculture and Innovation has asked to carry out a risk analysis of *V. spiralis*. The present report assesses relevant available knowledge and data which is subsequently used to perform a risk analysis of this species.

1.2 Research goals

The major goals of this study are:

- To perform a risk analysis based on the probability of arrival, establishment and spread, endangered areas, the (potential) ecological, socio-economic and public health impacts of *V. spiralis* in the Netherlands.
- To assess the dispersion, invasiveness and (potential) ecological effects of *V. spiralis* in the Netherlands using the Belgian Invasive Species Environmental Impact Assessment (ISEIA) protocol.
- To describe effective risk management options for control of spread, establishment and negative effects of *V. spiralis* into and within the Netherlands.

1.3 Outline and coherence of research

The present chapter describes the problem statement, goals and research questions in order to undertake a risk analysis of *V. spiralis* in the Netherlands (described above). Chapter 2 gives the methodological framework of the project, describes the Belgian ISEIA protocol and approaches used to assess socio-economic risks, public health risks and management approaches applicable in the Netherlands. Chapter 3 describes the results of the risk assessment, assesses the probability of arrival, establishment and spread, summarises the results of the literature study of socio-economic and public health risks and analyses risk management options. Chapter 4 discusses gaps in knowledge and uncertainties, other available risk analyses and explains differences between risk classifications. Chapter 5 draws conclusions and gives recommendations for further research. An appendix with background information in the form of a

knowledge document completes this report. The coherence between various research activities and outcomes of the study are visualised in a flow chart (Figure 1.1).

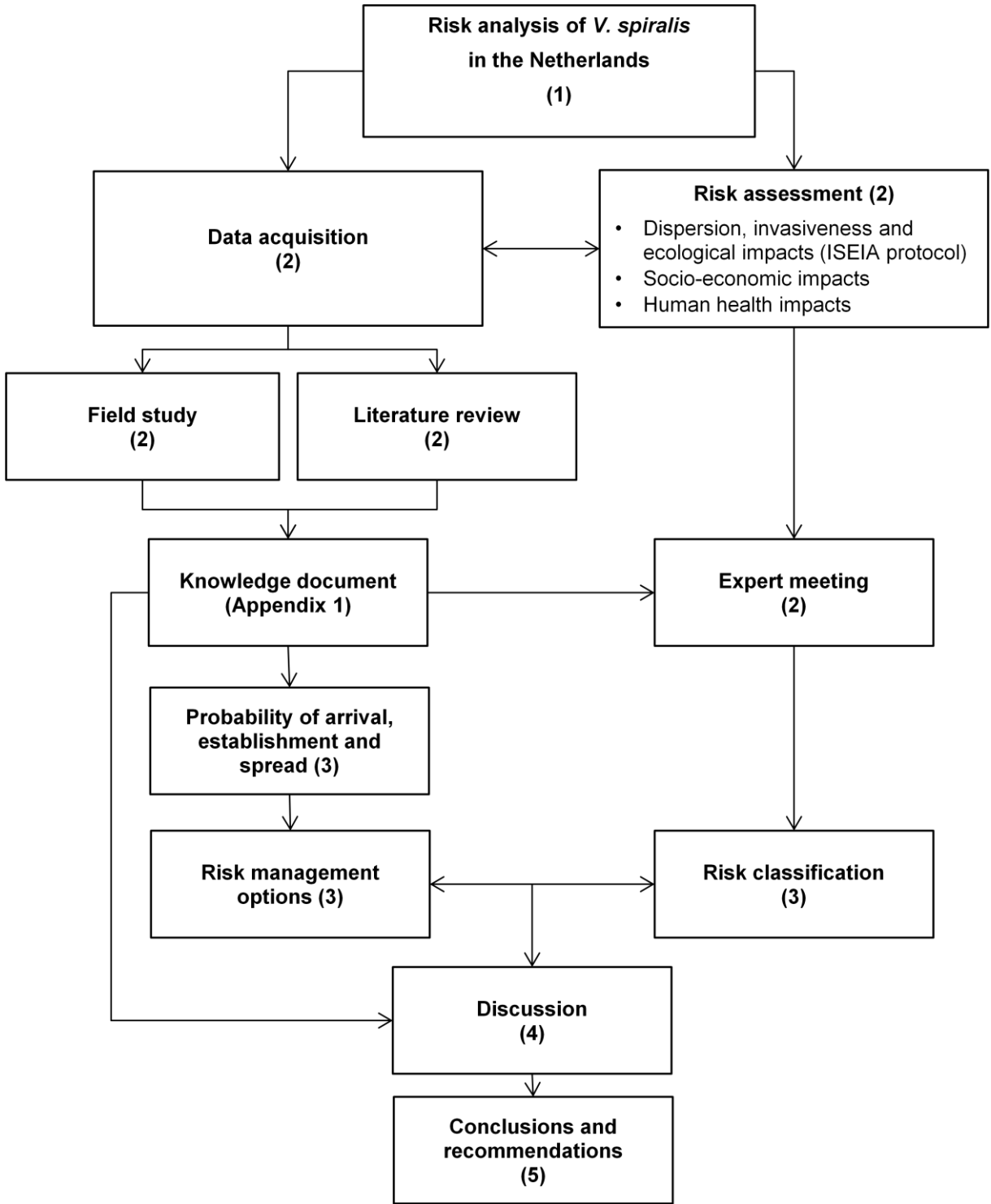


Figure 1.1: Flowchart visualising the coherence of various components of the risk analysis of Tapegrass (*Vallisneria spiralis*) in the Netherlands. Chapter numbers are indicated in brackets.

2. Methods

2.1 Components of risk analysis

The risk analysis of Tapegrass (*Vallisneria spiralis*) in the Netherlands was comprised of analyses of probability of arrival into and within the Netherlands, establishment and spread within the Netherlands and an ecological risk assessment using the Belgian Invasive Species Environmental Impact Assessment (ISEIA), developed by the Belgian Biodiversity Platform (Branquart, 2007; ISEIA, 2009). Separate assessments of socio-economic, public health impacts and risk management options were made. Background information and data used for the risk analysis was summarised in the form of a separate knowledge document (Section 2.2).

2.2 Knowledge document

A literature search and data analysis describing the current body of knowledge with regard to taxonomy, habitat preference, dispersal mechanisms, current distribution, ecological and socio-economic impacts and management options for *V. spiralis* was undertaken. The results of the literature search were presented in the form of a knowledge document (Collas *et al.*, 2012; Appendix 1) and distributed to an expert team in preparation for the risk assessment.

2.3 Risk assessment

2.3.1 Dispersal potential, invasiveness and ecological impacts

The ISEIA protocol assesses risks associated with dispersion potential, invasiveness and ecological impacts only (Branquart, 2007). The *V. spiralis* risk assessment was carried out by an expert team. This team consists of five individuals. One from the Netherlands Food and Consumer Product Safety Authority; one from the Dutch plant research and conservation organisation FLORON; one from the Roelf Pot Research and Consultancy firm and two from the Radboud University, Nijmegen. Each expert completed an assessment form independently, based on the contents of the knowledge documents. Following this preliminary individual assessment, the entire project team met, elucidated differences in risk scores, discussed diversity of risk scores and interpretations of key information. The results of these discussions were presented in an earlier draft of this report. Following the submission of this draft version to the expert team, further discussion led to agreement on consensus scores and the level of risks relating to the four sections contained within the ISEIA protocol (Table 2.1).

Table 2.1: Definitions of criteria for risk classifications per section used in the ecological risk assessment protocol (Branquart, 2007; ISEIA, 2009).

1. Dispersion potential or invasiveness risk	
Low	The species does not spread in the environment because of poor dispersal capacities and a low reproduction potential.
Medium	Except when assisted by man, the species doesn't colonise remote places. Natural dispersal rarely exceeds more than 1 km per year. However, the species can become locally invasive because of a strong reproduction potential.
High	The species is highly fecund, can easily disperse through active or passive means over distances > 1km / year and initiate new populations. Are to be considered here plant species that take advantage of anemochory, hydrochory and zoochory, insects like <i>Harmonia axyridis</i> or <i>Cemeraria ohridella</i> and all bird species.
2. Colonisation of high conservation habitats risk	
Low	Population of the non-native species are restricted to man-made habitats (low conservation value).
Medium	Populations of the non-native species are usually confined to habitats with a low or a medium conservation value and may occasionally colonise high conservation habitats.
High	The non-native species often colonises high conservation value habitats (i.e. most of the sites of a given habitat are likely to be readily colonised by the species when source populations are present in the vicinity) and makes therefore a potential threat for red-listed species.
3. Adverse impacts on native species risk	
Low	Data from invasion histories suggest that the negative impact on native populations is negligible.
Medium	The non-native is known to cause local changes (<80%) in population abundance, growth or distribution of one or several native species, especially amongst common and ruderal species. The effect is usually considered as reversible.
High	The development of the non-native species <u>often</u> causes local <u>severe</u> (>80%) population declines and the reduction of local species richness. At a regional scale, it can be considered as a factor for precipitating (rare) species decline. Those non-native species form long standing populations and their impacts on native biodiversity are considered as hardly reversible. Examples: strong interspecific competition in plant communities mediated by allelopathic chemicals, intra-guild predation leading to local extinction of native species, transmission of new lethal diseases to native species.
4. Alteration of ecosystem functions risk	
Low	The impact on ecosystem processes and structures is considered negligible.
Medium	The impact on ecosystem processes and structures is moderate and considered as easily reversible.
High	The impact on ecosystem processes and structures is strong and difficult to reverse. Examples: alterations of physico-chemical properties of water, facilitation of river bank erosion, prevention of natural regeneration of trees, destruction of river banks, reed beds and / or fish nursery areas and food web disruption.

The ISEIA protocol contains twelve criteria that match the last steps of the invasion process (i.e., the potential for spread establishment, adverse impacts on native species and ecosystems). These criteria are divided over the following four risk sections: (1) dispersion potential or invasiveness, (2) colonisation of high conservation habitats, (3) adverse impacts on native species, and (4) alteration of ecosystem functions. Section 3 contains sub-sections referring to (i) predation / herbivory, (ii) interference and exploitation competition, (iii) transmission of diseases to native species (parasites, pest organisms or pathogens) and (iv) genetic effects such as hybridisation and introgression with native species. Section 4 contains sub-sections referring to (i) modifications in nutrient cycling or resource pools, (ii) physical modifications to habitats (changes to hydrological regimes, increase in water turbidity, light interception, alteration of river banks, destruction of fish nursery areas, etc.), (iii) modifications to natural successions and (iv) disruption to food-webs, i.e. a modification to lower trophic levels through herbivory or predation (top-down regulation) leading to ecosystem imbalance.

Each criterion of the ISEIA protocol was scored. Scores range from 1 (low risk) to 2 (medium risk) and 3 (high risk). Definitions for low, medium and high risk, according to the four sections of the ISEIA protocol are given in table 2.1. If knowledge obtained from the literature review was insufficient, then the assessment was based on expert judgement and field observation leading to a score of 1 (unlikely) or 2 (likely). If no answer could be given to a particular question (no information) then no score was given (DD - deficient data). Finally, the highest score within each section was used to calculate the total score for the species.

Consensus on the risk score of each section was reached using a hierarchical method where evidence from within the Netherlands was given priority over evidence derived from impacts occurring outside the Netherlands. It was also considered that the suitability of habitats in the Netherlands may change due to e.g. water temperature rise due to climate change. Moreover, consideration was given to the future application or non-application of management measures that will affect the invasiveness and impacts of this invasive plant in the Netherlands.

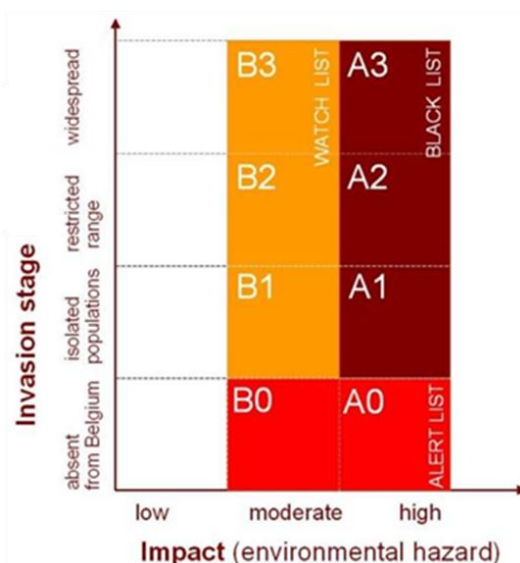


Figure 2.1: List system to identify species of most concern for preventive and mitigation action (Branquart, 2007; ISEIA, 2009).

Subsequently, the Belgian Forum Invasive Species (BFIS) list system for preventive and management actions was used to categorise the species of concern (Branquart, 2007; ISEIA, 2009). This list system was designed as a two dimensional ordination (Environmental impact * Invasion stage; Figure 2.1). This list system is based on guidelines proposed by the Convention on Biological Diversity (CBD decision VI/7) and the European Union strategy on invasive non-native species. Environmental impact of the species was classified based on the total risk score (global environmental risk) which is converted to a letter / list: score 4-8 (C), 9-10 (B - watch list) and 11-12 (A - black list). This letter is then combined with a number representing invasion stage: (0) absent, (1) isolated populations, (2) restricted range, and (3) widespread.

2.3.2 Socio-economic and public health impacts

Potential socio-economic and public health impacts did not form a part in the risk analysis according to the ISEIA protocol. However, these potential risks should be considered in an integrated risk analysis. Socio-economic risks were examined as part of the literature study (Collas *et al.*, 2012) and in discussions with project partners. Socio-economic risks occurring at present or in the future dependent on alterations in habitat suitability and management interventions were considered.

2.4 Risk management options

Management options were examined as part of the literature study and extensively described in the knowledge document (Appendix 1) and in discussions with project partners. A description of effective management options is given. These are specifically relevant to, and therefore recommended for, the Netherlands.

3. Risk analysis

3.1 Probability of arrival

Tapegrass (*Vallisneria spiralis*) has been recorded in the Netherlands since 1960. However, the current recorded distribution of *V. spiralis* is characterised by isolated populations. Further introductions may result in a widened distribution of *V. spiralis* in the Netherlands.

Since *V. spiralis* is a widely used aquarium plant, the main route of introduction is most likely the ornamental trade (Hussner & Lösch, 2005; Thiébaud, 2007; Martin & Coetzee, 2011; Hussner, 2012). The increase in e-commerce has exacerbated the problem of invasive plant sale giving international retailers the ability to advertise online and send plants in the post (Kay & Hoyle, 2001). Once bought, unwanted plants may be disposed of in the freshwater system. The results of a recent survey examining the behaviour of consumers of aquatic plants in the Netherlands showed that 2% of the 230 respondents had disposed of aquatic plants in open water (Verbrugge *et al.*, 2011). Moreover, in Dutch waters, common garden pond plants occur with examples of pumpkinseed sunfish (*Lepomis gibbosus*). This fish species was introduced to the Netherlands in 1902 as an aquarium and garden pond fish (Van Kleef *et al.*, 2008). This gives further credence to species disposal as a potential route for the introduction of invasive plants and animals.

A Google search was conducted to assess the availability of *V. spiralis* for sale. The species was advertised by both commercial and hobbyist websites (Figure 3.1 and 3.2). No commercial websites were found for the Dutch name: *Vallisneria*. However, for both the search term *V. spiralis* and *Vallisneria* numerous hobbyists were found that were selling the species (Figure 3.1). The main providers of *V. spiralis* are hobbyists offering plants for sale on discussion boards.

We predict that without management intervention, *V. spiralis* introductions will continue, leading to a potential further increase in its distribution within the Netherlands.

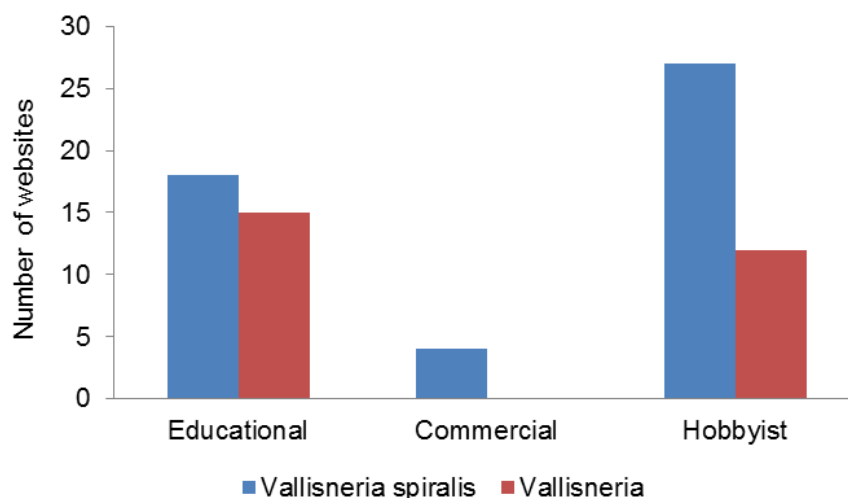


Figure 3.1: The different types of websites with different search terms in Google.nl.

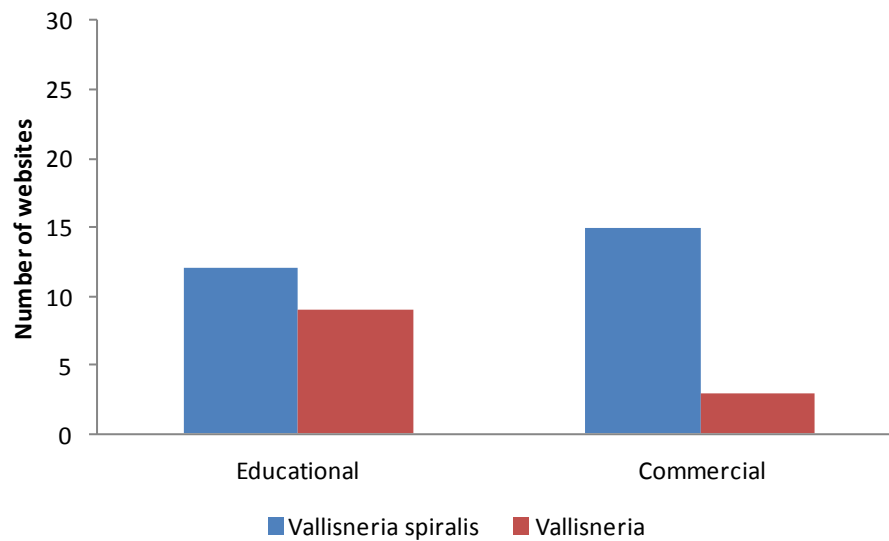


Figure 3.2: The types of discussion performed in the hobbyist discussion boards websites found through Google.nl.

3.2 Probability of establishment

V. spiralis was first recorded in the Netherlands in 1960 in the Maastricht-Luik canal in Maastricht. A year later, another large site was discovered nearby at the southern part of the spillway Bosscherveld. These recordings coincided with the expansion of *V. spiralis* along the river Meuse in Belgium around 1955 (Ooststroom & Reichelt, 1961; Ooststroom & Reichelt, 1963). In 2005 a population was observed in a brook near Eijsden. It is uncertain if the species is still present in the Maastricht area.



Figure 3.3: (a) The habitat of Tapegrass (*Vallisneria spiralis*) near the Zuid-Maartengat during winter. (b) The habitat of *V. spiralis* near the Dam van England (Photos: A. Boesveld).

V. spiralis is almost invisible from the water surface at most locations. The plants were first discovered in the Biesbosch area in 2001 by divers (Boesveld, personal communication). Figure 3.3 shows two locations where *V. spiralis* was found. The real extent of its presence became clear in 2011 when, at low tide and in a period of low river discharge, leaves protruded above the water surface (Van der Neut & Muusse, 2011). *V. spiralis* has been recorded within at least 8 square-kilometres at this location.

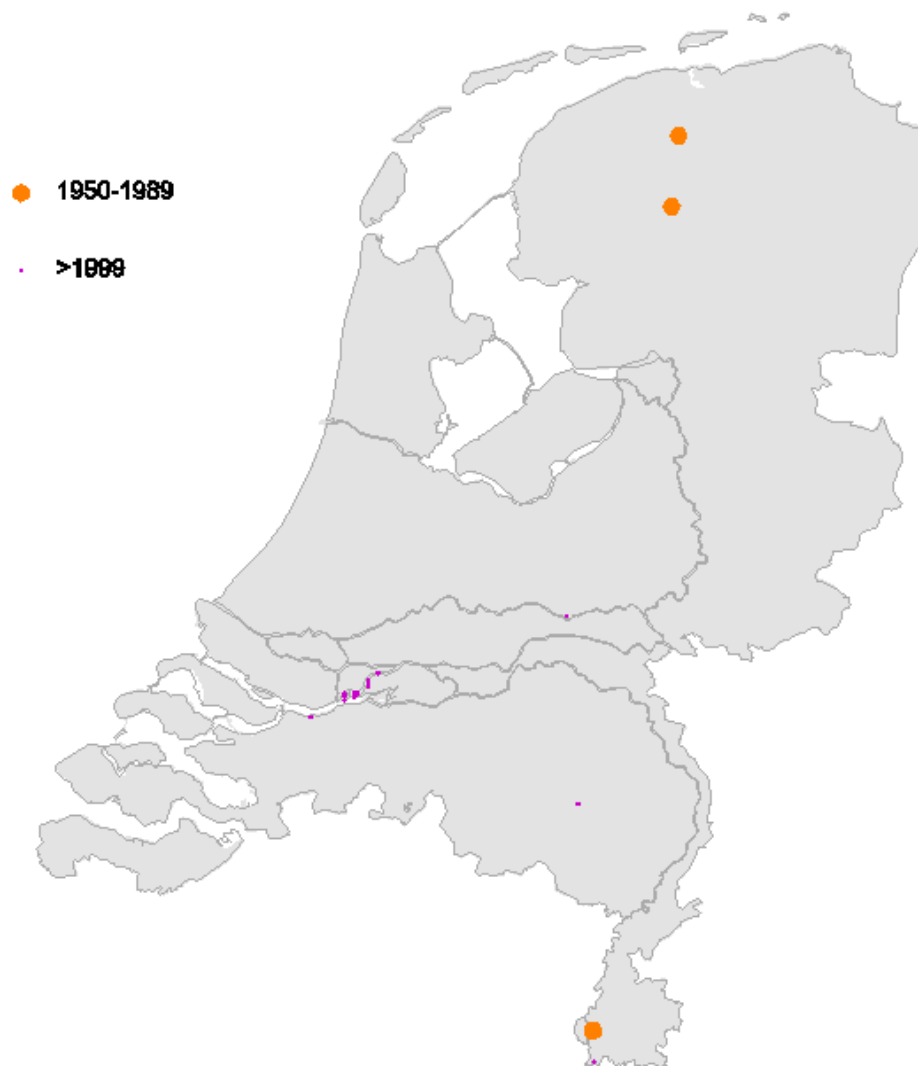


Figure 3.4: The distribution of Tapegrass (*Vallisneria spiralis*) in the Netherlands (National Database Flora en Fauna, complemented with data sources described in Collas *et al.*, 2012 and Beringen, 2012).

The first known record of *V. spiralis* was in 1960. Throughout the 20th century the records of *V. spiralis* varied between 1 and 2 kilometre squares. During the 21st century the number of kilometre squares containing *V. spiralis* with confirmed records increased to a total of thirteen in 2012 (Figure 3.4). Most kilometre squares are located in the intertidal freshwater estuarine areas of the rivers Rhine and Meuse (Biesbosch – Merwede – Hollandsch Diep area). Only two squares are located outside this area; one in the Eindhovenens canal and a second one in a sand excavation pit near Grebbeberg. The recorded distribution of *V. spiralis* is characterised by isolated populations. However, its actual distribution may be more extensive as it is a very inconspicuous species. Most locations are almost invisible from on shore or from a boat.

At some locations in the intertidal freshwater estuarine areas of the rivers Rhine and Meuse (Biesbosch-Merwede area) several thousand specimens have been observed, the species has been present at some locations for more than 11 years (Beringen,

2012). Moreover, there is recent evidence of a significant increase in the distribution of *V. spiralis* within the Nieuwe Merwede river (Boesveld, personal communication).



Figure 3.5: Tapegrass (*Vallisneria spiralis*) collected at water depth 50 cm in the Dordtsche Biesbosch, Zuid Maartengat, The Netherlands. At this site shells of the invasive Asiatic Clam (*Corbicula fluminea*) and Zebra Mussel (*Dreissena polymorpha*) were also present (Photo: J.L.C.H. van Valkenburg).

In the Netherlands, *V. spiralis* grows to a depth of 40-100 cm in water bodies with tidal fluctuations of about 30 cm. The pH of these sites varied between 7.96 and 8.48, the alkalinity between 113 and 123 mg l⁻¹ and the Secchi depth between 55-75 cm (Table 3.1). In the Biesbosch, along the river Merwede, *V. spiralis* seems to prefer the lower reaches of tidal creeks and grows over a wide area in the Zuid Maartensgat. At some sites in the Biesbosch, native mussels (Unionidae) and non-native mussels (*Corbicula* and *Dreissena*) are very abundant (Figure 3.5).

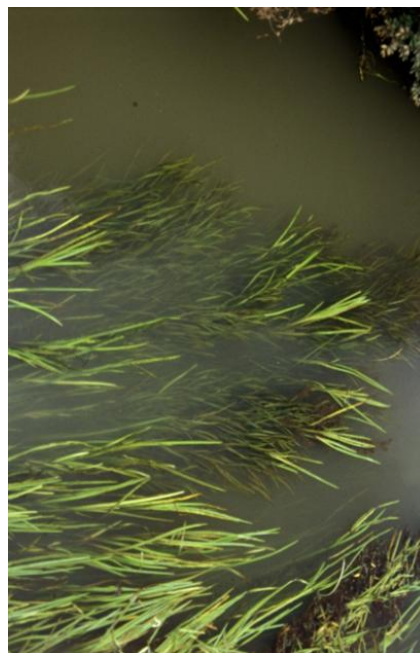


Figure 3.6: Tapegrass (*Vallisneria spiralis*) in a side-branch of the river Erft at Kasterer Mühlen, Northrhine-Westphalia, Germany (Photo: A. Hussner).

An overview of physiological conditions tolerated by *V. spiralis* obtained from worldwide records is shown in table 3.1. The species has been recorded in water bodies with a wide variety of temperatures (18.1-39 °C) and does not tolerate water temperatures below 5 °C. Besides the water temperature the species can tolerate slightly acidic to slightly alkaline conditions (Table 3.1). The plant is present to a maximum depth of 6.5 m and prefers clear water. *V. spiralis* can be found in both still and flowing waters and has a high tolerance to wave stress (Ali *et al.*, 1999; Hussner & Lösch, 2005; Al-Asadi *et al.*, 2007). The species occurs on muddy, sandy and gravelly sediment and can tolerate low light conditions due to a low light compensation point (Hussner & Lösch, 2005; Mukhopadhyay & Dewanji, 2005; Ye *et al.*, 2009). The species can form thick beds in the littoral zone of ponds and lakes (e.g. see figure 3.6) and has a maximum biomass of 3632 gram dry weight per m⁻² (Royle & King, 1991; Mukhopadhyay *et al.*, 2007).

Table 3.1: Physiological conditions tolerated by Tapegrass (*Vallisneria spiralis*).

Parameter	Published data	References
Water Temperature (°C)	18.1 - 39	Ejsmont-Karabin & Hutorowicz (2011); Ali <i>et al.</i> (2011); Rachetti <i>et al.</i> (2010); Rai & Tripathi (2009); Al-Asadi <i>et al.</i> (2007); Mukhopadhyay & Dewanji (2004); Jana & Choudhuri (1984)
Minimum Temperature (°C)	5	Kasselmann (2009)
pH	4.3 - 8.8 ^a 2.9 ^b	Ali <i>et al.</i> (2011); Rachetti <i>et al.</i> (2010); Rai & Tripathi (2009); Ye <i>et al.</i> (2007); Al-Asadi <i>et al.</i> (2007); Mukhopadhyay & Dewanji (2005); Hussner & Lösch (2005)
	7.96 - 8.48	Field study
Alkalinity (mg l ⁻¹)	63 - 290	Rai & Tripathi (2009)
	113 - 123	Field study
Nitrate (mg l ⁻¹)	0.84 - 391	Rai & Tripathi (2009); Ye <i>et al.</i> (2007); Mukhopadhyay & Dewanji (2005); Hussner & Lösch (2005); Mukhopadhyay & Dewanji (2004)
Phosphate (mg l ⁻¹)	0.02 - 10.4	Rai & Tripathi (2009); Ye <i>et al.</i> (2007); Mukhopadhyay & Dewanji (2005); Hussner & Lösch (2005); Mukhopadhyay & Dewanji (2004)
Depth (cm ⁻¹)	10 - 650	Ali <i>et al.</i> (2011)
Secchi disc visibility (cm ⁻¹)	63 - 167	Ye <i>et al.</i> (2007); Mukhopadhyay & Dewanji (2005); Mukhopadhyay & Dewanji (2004)
	55 - 75	Field study
Dissolved oxygen (mg l ⁻¹)	0.96 - 20.3	Ejsmont-Karabin & Hutorowicz (2011); Ali <i>et al.</i> (2011); Rachetti <i>et al.</i> (2010); Ye <i>et al.</i> (2007); Al-Asadi <i>et al.</i> (2007)
Flow velocity (m s ⁻¹)	0 - 0.8	Hussner & Lösch (2005)
Conductivity (µS cm ⁻¹)	104 - 1990	Ali <i>et al.</i> (2011); Rachetti <i>et al.</i> (2010); Hussner & Lösch (2005)

^a Generic range found for the pH; ^b Incidental pH value.

V. spiralis can experience different types of stress in its habitat. In the case that the species is exposed to habitat with heterogeneous nutrient availability and light conditions it produces more ramets in favourable patches, thereby enabling escape from low nutrient and low light patches (Xiao *et al.*, 2006a; Xiao *et al.*, 2006b; Wang & Yu, 2007; Xiao *et al.*, 2007; Zhao *et al.*, 2012). Another type of stress the plants experience is sedimentation stress, which occurs in turbid waters (Hussner & Lösch, 2005). A decrease in relative growth was found when the species was exposed to high sedimentation levels (i.e. sedimentation of eight cm sand; Li & Xie, 2009). However, at lower sedimentation levels *V. spiralis* showed two escape mechanisms to avoid the negative effects of sedimentation: the runners were developed in a decreased angle and the runner was elongated thereby placing the ramets closer to the sediment surface. A high water turbulence between 1.61 and 2.86 cm s⁻¹ was also found to decrease the growth of the species (Ellawala *et al.*, 2011).

Ye *et al.* (2009) recorded that *V. spiralis* achieves the highest growth rate on fertile sediments. The growth rate itself was found to vary during the year. Pinardi *et al.* (2009) calculated that the net growth rate (NGR) of leaves was 0.001 d⁻¹ during the winter and 0.08 d⁻¹ during the summer. The leaf NGR was calculated using an exponential growth model and measurements of leaf length and width. Gao *et al.* (2009) found a relative growth rate of 0.1, calculated as the ratio of dry weight difference between dry weight at the end of 30 days of incubation and dry weight at the beginning of the experiment.

The pH values, alkalinity and depth measured during the field study at *V. spiralis* locations in the Netherlands were within the world wide ranges recorded for this species. The minimum Secchi depth in the Netherlands was slightly below reported values for other regions.

After considering the above information on physiological tolerances, growth performance and current occurrence it is expected that the establishment of *V. spiralis* in the Netherlands will be mainly limited by the minimum water temperature. The winter temperature in most inland water bodies in our country will be below the tolerance value of *V. spiralis*. This particularly holds for the shallow parts of rivers and lakes. Therefore, the probability of establishment based on current available data, away from the intertidal freshwater estuarine areas of the rivers Rhine and Meuse, was judged to be low.

3.3 Probability of spread

A possible dispersal mechanism of *V. spiralis* is the transport of seeds through waterfowl (Hussner & Lösch, 2005; Van Leeuwen, 2012). No cases of *V. spiralis* transport through endozoochory are known, however, there are known cases for the same order as *V. spiralis*. Seeds have not been observed germinating in aquaria. Instead, plants most often propagate using runners which can lead to dense stands. The species is able to reproduce vegetatively through fragmentation.

In the Netherlands *V. spiralis* is found in the Biesbosch area. It was first recorded in 2001 and persists at this site. This is a site of sparse human population suggesting dispersal and established of a sizeable population of *V. spiralis* may have occurred through natural means. Dispersal mechanisms may have been the transport of seeds and fragments through the rivers Rhine and Meuse. Seeds may also have been transported via waterfowl which are abundant in the Biesbosch. Seeds could potentially have originated in France where *V. spiralis* is known to occur.

Table 3.2: An overview of the vectors for dispersal of Tapegrass (*Vallisneria spiralis*).

Vector/Mechanism	Mode of transport	Importance to dispersal into and within the Netherlands	References
Aquarium trade	Emptying aquaria in nature, humans	High	Hussner & Lösch (2005); Thiébaud (2007); Martin & Coetzee (2011); Hussner (2012)
Natural, non-living	Water	High	Natural England (2011)
	Wind	Medium	Natural England (2011)
Dispersal through species	Waterfowl, aerial transport	Low	Hussner & Lösch (2005); Van Leeuwen (2012)

Besides the ornamental trade, humans also influence the temperature of rivers (Hussner & Lösch, 2005; Willby, 2007). River water temperature is increased due to discharge of cooling water and climate change. Higher river temperatures enables *V. spiralis* to spread into new habitats. Table 3.2 gives an overview of different vectors, both human and natural.

The species can easily disperse through wind, water, humans and birds. The potential habitat area of *V. spiralis* will increase due to climate change and the discharge of cooling water. The species is able to reproduce vegetatively and plant fragments are also capable of colonizing new areas.

After considering the above information the probability of spread was judged to be high.

Risk classification using the ISEIA protocol

3.3.1 Expert consensus scores

The total risk score attributed to *V. spiralis* was 7 out of a maximum risk score of 12. This results in an overall classification of low risk for this species.

Table 3.3: Consensus scores and risk classifications for Tapegrass (*Vallisneria spiralis*) in the current situation in the Netherlands.

ISEIA Sections	Risk classification	Consensus score
Dispersion potential or invasiveness	high risk	3
Colonization of high value conservation habitats	medium risk	2
Adverse impacts on native species	low risk	1
Alteration of ecosystem functions	low risk	1
Global environmental risk	C - list category	7

3.3.2 Dispersion potential or invasiveness

Classification: **High risk.** *V. spiralis* is able to reproduce vegetatively and can disperse via water (hydrochory), humans and bird vectors, displaying a strong reproductive potential. Since it was first recorded in the Netherlands in 1960, dispersal of *V. spiralis* has been slow and the distribution of records within the Netherlands remains isolated to five separate locations. There continues to be a market for *V. spiralis* in the Netherlands demonstrated by the availability of plants for sale online and plants maybe exchanged between hobbyists within the Netherlands and across international borders. This together with the possibility of voluntary disposal of plants by the public suggests that there is a continued risk of release of *V. spiralis* to the freshwater network. Moreover, records of *V. spiralis* may underestimate its actual distribution as plants are almost invisible if viewed from the water surface.

In future, the potential habitat area of *V. spiralis* may increase in the intertidal freshwater estuarine areas of the rivers Rhine and Meuse. Here, extreme low water levels do not occur during winter. This in combination with the occurrence of large areas of shallow water (1 m depth approximately) which warms rapidly in spring and summer and does not freeze to the bottom in winter, increases the suitability of this water type for *V. spiralis*. The addition of river water warmed by thermal discharges and of improved general quality increases this suitability. Moreover, river temperatures are expected to increase further in future due to climate change. This may result in an increase in dispersal potential and a revision of the risk classification.

3.3.3 Colonisation of high conservation value habitats

Classification: **Medium risk.** The only recent known areas of high conservation habitats colonized by *V. spiralis* in the Netherlands are the freshwater tidal area of the Biesbosch-Merwede and a sand excavation pit in the floodplains along the Nederrijn River near

Grebbeberg (both sites are located in a Natura 2000 area according to the European Habitats Directive and Birds Directive). The habitats in which the species grows within the Biesbosch-Merwede area are more or less comparable to Habitat type H3260 Water courses of plain to mountain levels (*Ranunculion fluitantis* and *Callitriche-Batrachion*). Spread of *V. spiralis* through natural means via water birds in wetlands like the Biesbosch may occur. It is possible for seeds to be transported over hundreds of kilometres (Van Leeuwen, 2012), for instance from southern over-wintering habitats (e.g. the Seine estuary) in the intestines of ducks. Therefore, the spread of *V. spiralis* to other high value nature areas, with or without the assistance of people, cannot be ruled out. The abundance of *V. spiralis* has not increased in the Eindhovens canal and excavation pit near Grebbeberg, while in the Biesbosch-Merwede area increases in abundance have been observed.

3.3.4 Adverse impacts on native species

Classification: **Low risk**. There is no evidence to suggest that the presence of *V. spiralis* has a negative impact relating to predation / herbivory, interference and exploitation competition, transmission of diseases to native species and genetic effects such as hybridisation and introgression with native species. Field observations suggest that there are no signs that native aquatic plant species are displaced by *V. spiralis* in the Biesbosch. *V. spiralis* has been present in other European countries, with more suitable climates, for longer periods than have been observed in the Netherlands. However, until now nowhere in these countries is *V. spiralis* regarded as a pest species. This is supported by evidence from the literature where only positive effects of *V. spiralis* are reported. Therefore, it is expected, even with a potential future range expansion, that negative impacts on native species will be minimal.

3.3.5 Alteration of ecosystem functions

Classification: **Low risk**. There is no evidence to suggest that the presence of *V. spiralis* has a negative impact relating to modifications in nutrient cycling or resource pools, physical modifications to habitats, modifications to natural successions and disruption to food-webs in the Netherlands. *V. spiralis* has been present in other European countries, with more suitable climates and for longer periods than have been observed in the Netherlands. Our literature review yielded no evidence for adverse alterations of ecosystem functioning by *V. spiralis* in other European countries. Therefore, it is expected, even with a potential future range expansion, that negative alterations to ecosystem function will be minimal.

3.3.6 Species classification

The species classification corresponds to global environmental risk score of the ISEIA (Table 3.1) combined with the current distribution of the non-native species within the country in question. The species classification for *V. spiralis* is C1 (Figure 3.7). This indicates a non-native species with isolated populations and low environmental hazard (ecological risk).

However, habitat alteration resulting from climate change may result in a future re-grading of risk. Future increases in water temperature may increase habitat availability for the colonisation of *V. spiralis*. This associated with favourable local habitat conditions specific to the intertidal freshwater estuarine areas of the rivers Rhine and Meuse may increase the area of suitable habitat for *V. spiralis* at these locations. Over the past century the minimum, average and maximum temperature of the rivers Rhine and Meuse increased due to thermal discharges and climate change (Leuven et al., 2011). In other areas an increase in habitat availability is likely to be limited due to the plants relatively low minimum temperature tolerance for survival. This is illustrated by the presence of warmer refuges in deeper water that do not appear to have influenced the distribution of *V. spiralis* in the past and the fact that *V. spiralis* has been recorded in the Netherlands since 1960 without an extensive increase in distribution. Moreover, there is a lack of reported negative impacts in other European countries where *V. spiralis* has been present for longer periods than in the Netherlands. Therefore, it is expected that impacts on native species and alterations to ecosystem functions will not alter from the present situation, even with a potential future range expansion. This would lead to the same low global environmental risk classification as is seen today (Table 3.4). In this theoretical scenario *V. spiralis* would remain in the C1 classification within the BFIS list system.

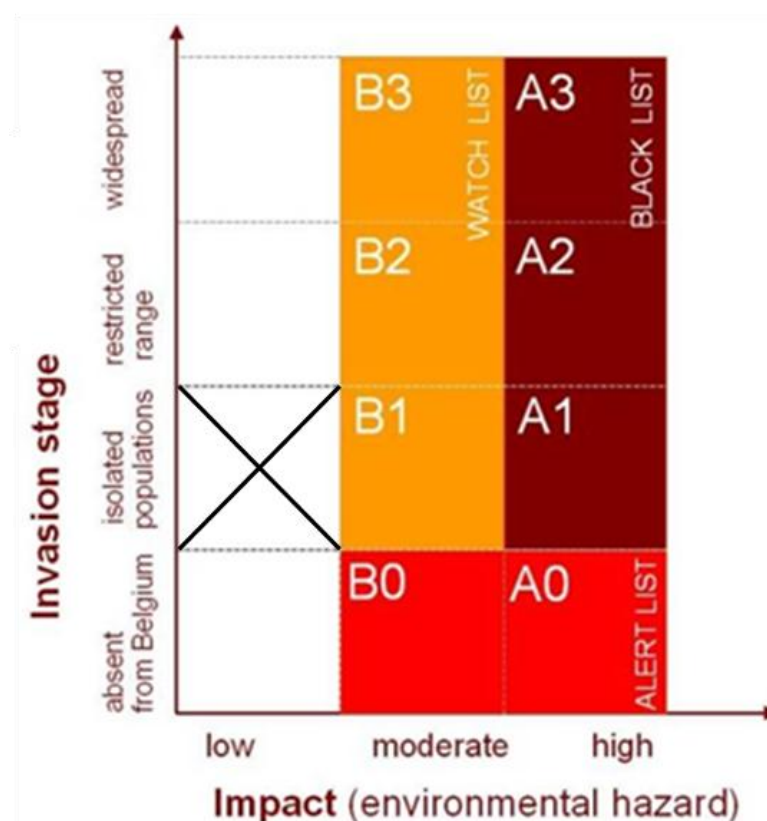


Figure 3.7: Tapegrass (*Vallisneria spiralis*) species classification according to the BFIS list system.

Table 3.4: Tapegrass (*Vallisneria spiralis*) species theoretical classification according to potential future habitat scenario.

ISEIA Sections	Risk classification	Consensus score
Dispersion potential or invasiveness	high risk	3
Colonization of high value conservation habitats	medium risk	2
Adverse impacts on native species	low risk	1
Alteration of ecosystem functions	low risk	1
Global environmental risk	C - list category	7

3.4 Socio-economic impacts

There is little evidence of socio-economic impacts related to *V. spiralis* in the Netherlands. *V. spiralis* is known to affect the drainage of different water bodies as well as impede recreational use (CABI, 2012). *V. spiralis* can be used to remove heavy metals and organic compounds from effluents thereby improving its physico-chemical properties (Shukla et al., 2009; Du et al., 2007; Di Marzio et al., 2005; Yan et al., 2011). However, the positive effects resulting from bioaccumulation are not unique for *V. spiralis*, the majority of submerged aquatic plants have similar effects.

3.5 Public health effects

There was no information found concerning the public health effects of *V. spiralis* during the literature study or in communications with project partners.

3.6 Risk management

3.6.1 Prevention

The main distribution channel or vector for the spread of *V. spiralis* is the trade in plants for aquaria and garden ponds. The species may be replaced by *Sparganium emersum*, a more benign species, in the plant trade. Plants are also sold under the names *Vallisneria americana* and *Vallisneria gigantea* but the taxonomic status of these alternatives are unclear. These plants may be a more potent strain of *V. spiralis*, which makes them an even more risky alternative. Currently, in the Netherlands, a campaign is underway that aims to prevent further introductions and spread by making consumers and employees from garden centres and plant nurseries more aware of the problems with non-native species. The name of this campaign is 'Geen exoot in de sloot'. Its effectiveness is currently being examined (Verbrugge et al., 2011). *V. spiralis* can be kept in isolation to prevent release from aquaria, with the cooperation of the owners. However, there is no feasible option for preventing spread of species after establishment in the freshwater network. *V. spiralis* cannot be stopped from autonomously dispersing through fragmentation or through the deployment of runners.

Public awareness is an important component in a strategy aimed at controlling or removing an invasive species from a catchment area. This is especially true of species

such as *V. spiralis* where people are a major vector of dispersal. Awareness leaflets, press releases, calendars, lakeside notifications and an information website, warning of the environmental, economic and social hazards posed by this plant will contribute to public awareness (Caffrey & O'Callaghan, 2007).

Education of anglers and boaters may be especially useful as they can assist in reporting sightings of the plant.

3.6.2 Elimination

Once the plants have established eradication is very difficult. The best option to eliminate the species is through isolation of local populations. Natural disappearance should follow. Natural disappearance of isolated populations of *V. spiralis* has occurred near Eijsden and Maastricht and at other known sites in the Netherlands.

3.6.3 Control

There is no experience with species-specific control measures in the Netherlands. If control is required the best method is the removal of leaf biomass by weed cutting boats. Weed cutting boats are an example of active mechanical removal and are equipped with cutter bars coupled to a hydraulic control (Figure 3.8). This allows the depth and angle of the cutter bar to be adjusted in the water. Plants are cut more efficiently than with passive cutting boats. However, mechanical removal may result in the breakup of plant stems resulting in the dispersal of plants to new areas (Bowmer *et al.*, 1995). The dispersal of plant fragments and subsequent vegetative reproduction has been observed following the mechanical removal of the invasive Curly waterweed (*Lagarosiphon major*) in the Netherlands (R. Pot, unpublished results). Therefore, it is recommended that *V. spiralis* is cut at a minimum height of 20 cm above the stem base to prevent spread of viable fragments with stolons or roots.



Figure 3.8: A weed cutting boat with adjustable mowing gear used for aquatic weed control in the Netherlands (Photo: R. Pot).

4. Discussion

4.1 Risk assessment

A lack of information in the literature on the (potential) impact of Tapegrass (*Vallisneria spiralis*) in the Netherlands has resulted in a reliance on expert knowledge and field observations to judge the risk level of certain criteria. There is a lack of clarity regarding the taxonomic status of certain species. Moreover, it is not clear if only *V. spiralis* is circulated in the plant trade and present in the wild, or if other species, such as *Vallisneria americana*, are also present. The importance of water birds to the dispersal of *V. spiralis* in the Netherlands compared to other dispersal mechanisms is also unknown. This lack of information may be a reflection of the observed limited distribution of *V. spiralis* in the Netherlands at the present time.

V. spiralis is categorised as C1 (isolated populations and low environmental hazard) in the BFIS list system based on current records in the Netherlands. However, *V. spiralis* is a very inconspicuous species, plants grow beneath the surface of the water making most sites almost invisible from on shore or from a boat. The real extent of *V. spiralis* presence in the Biesbosch only became clear in 2011 when, at low tide and in a period of low river discharge, leaves protruded above the water surface (Van der Neut & Muusse, 2011). Therefore, there may well be discrepancies between the actual distribution and the recorded distribution of *V. spiralis* within the Netherlands. If the actual distribution of *V. spiralis* is higher than the recorded distribution then a re-classification of the species to a higher BFIS category may be required, for example to C2.

Future changes, such as increases in water temperature associated with climate change, may result in an increase in the distribution of *V. spiralis* in the Dutch freshwater network as well as in isolated water bodies. Therefore, the risk of impacts may have to be reassessed in future in view of greater potential impacts.

The ISEIA protocol is limited to an assessment of invasiveness and ecological impacts. Socio-economic impacts or impacts to human health were therefore considered separately.

Risk criteria in the ISEIA protocol were sometimes restrictive, as there was an absence of quantitative data that allowed the criteria to be assessed e.g. 1 km per year dispersal criterion for the 'dispersion or invasiveness' section.

4.2 Comparison of available risk classifications

No examples could be found where the ISEIA protocol was applied to assess the risk of *V. spiralis* in other countries.

Two risk assessments have been carried out for Tapegrass (*Vallisneria spiralis*). One risk assessment was performed in New Zealand and used the aquatic weed risk assessment model (AWRAM) with a minimum value of 4 and a maximum value of 100 (Champion & Clayton, 2000). *V. spiralis* scored a 51 and was thus listed as a

surveillance pest plant in New Zealand. However, the species assessed is now known as *Vallisneria australis* (Paul Champion, personal communication, 23 July 2012). The other assessment was carried out in Great Britain (Natural England, 2011) and was based on the Australian Weed Risk Assessment (Pheloung, 1995). *V. spiralis* was classified as an urgent species with a score of 22 and a potential score of 28 (Natural England, 2011).

The high risk associated with *V. spiralis* to native species and ecosystem functions in other countries may be a function of a greater habitat suitability and resultant high level of invasiveness in those countries.

4.3 Risk management

Banning of sale of invasive plants via the plant trade continues to be the most potentially effective method of controlling the spread of invasive plant species. Once *V. spiralis* is released to the environment, control and elimination becomes more difficult.

Management by mechanical means has been recommended for the control and possible elimination of the species. However, managers may first wish to consider observing the dispersal potential of individual populations of *V. spiralis* prior to instigating active management. If populations become problematic (e.g. cause restriction in water flow), isolation may be considered as this will facilitate the elimination of the species. Isolated populations of *V. spiralis* have disappeared naturally in Eijsden and Maastricht and other locations within the Netherlands. Costs and the risk of a facilitation of reproduction through fragmentation together with the limited dispersal potential of *V. spiralis* observed in the Netherlands since 1960, count against the early implementation of weed cutting measures.

V. spiralis is classified in the low risk category of the ISEIA protocol. Although *V. spiralis* has been recorded in the Netherlands since 1960, its distribution is still characterised by isolated populations. Moreover, no impacts on native species or on the functioning of ecosystems have been recorded in the Netherlands. It is not expected that the distribution of *V. spiralis* will increase significantly in the future. Therefore, there is no basis to recommend that restrictions on the sale of *V. spiralis* are required in the Netherlands. Only sterile examples of *V. spiralis*, indigenous to southern Europe, are sold in the plant trade and these plants are difficult to separate from other species in the genus *Vallisneria*. Plant traders should ensure that it is *V. spiralis* that is being sold and not the similar *V. americana*, as the probability of establishment, spread and the potential impacts of this second species are currently unclear.

5. Conclusions and recommendations

The main conclusions and recommendations of the risk analysis of non-native Tapegrass (*Vallisneria spiralis*) in the Netherlands are as follows:

- Plants arrive via the plant trade and may be released to the freshwater network by hobbyists. The species is able to reproduce vegetatively and can arrive via water, humans and bird vectors, displaying a strong reproductive potential. We predict that without management intervention, *V. spiralis* introductions will continue leading to a potential increase in its distribution. The probability of arrival was judged to be high.
- Since it was first recorded in the Netherlands in 1960, the rate of establishment of *V. spiralis* has been slow and records remain limited to five separate locations. Currently, the only known habitats of *V. spiralis* in the Netherlands are the freshwater tidal area of the Biesbosch-Merwede and a sand excavation pit in the floodplains along the Nederrijn River near Grebbeberg (both sites are located in a Natura 2000 area). The abundance of *V. spiralis* in the Biesbosch-Merwede has increased, while in the sand excavation pit near Grebbeberg an increase in abundance has not been observed.
- Due to its strong reproductive potential and the existence of multiple human and natural vectors, the spread of *V. spiralis* to other high value nature areas cannot be ruled out.
- The probability of establishment outside the intertidal freshwater estuarine areas of the rivers Rhine and Meuse, based on current available data on physiological tolerances, was judged to be low. Low minimum water temperature during severe winters will limit establishment of *V. spiralis* in shallow parts of many inland waters.
- The actual distribution of *V. spiralis* may be more extensive as it is a very inconspicuous species. Most locations are almost invisible from on shore or from a boat. It is recommended that the monitoring of *V. spiralis* is continued, and takes into account the difficulties associated with locating the plant.
- *V. spiralis* displays a strong reproductive potential by producing seeds and can spread in the form of fragments that may be transported in water or by waterfowl. However, plants most often spread using runners which can lead to dense stands. The probability of spread was judged to be high.
- There is no evidence to suggest that *V. spiralis* has a negative impact on native species in the Netherlands. Field observations suggest that there are no signs that native aquatic plant species are displaced by *V. spiralis* in the Biesbosch- Merwede area. *V. spiralis* has been present in other European countries, with more suitable climates, for longer periods than have been observed in the Netherlands. However, nowhere in these countries is *V. spiralis* regarded as a pest species. Therefore, it is expected, even with a potential future range expansion, that negative impacts on native species will be minimal.

- No adverse effects of *V. spiralis* on ecosystem functioning in the Netherlands were identified. In addition, there is no evidence for adverse alterations of ecosystem functioning from other European countries with more suitable climates and where this species has been present for a longer period than in the Netherlands. Therefore, it is expected that in the future, even with a potential range expansion, that negative alterations to ecosystem function will be minimal.
- *V. spiralis* is rated as a low risk species for ecological impacts according to the ISEIA protocol. According to recorded distributions and risk score, *V. spiralis* is classified as a C1 species in the BFIS list system.
- Information from other countries indicates that *V. spiralis* is known to affect the drainage of different water bodies as well as impede recreational use.
- Socio-economic impacts resulting from *V. spiralis* have not been identified in the Netherlands.
- No human health impacts resulting from *V. spiralis* have been identified for the Netherlands.
- Due to the low impact of *V. spiralis* on native species and ecosystem functions it is recommended that populations are observed. Active management through isolation is recommended only if populations become problematic (e.g. cause restriction in water flow).
- The early implementation of weed cutting is not recommended due to cost and the potential for further dispersal of *V. spiralis* by fragmentation.
- There is no basis to recommend restrictions on the sale of *V. spiralis* in the Netherlands. Plant traders should ensure that it is *V. spiralis* that is being sold and not the similar *V. americana*, as the probability of establishment, spread and the potential impacts of this second species are currently unclear.

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8. Appendices

Appendix 1. Knowledge document used for the risk analysis